Understanding spatial variations in accessibility to banks using variable floating catchment area techniques

Abstract

In response to changing consumer habits driven by the advance of online services and mobile apps, substantial reductions in the provision of bank branches have been widely documented over the last decade. Such closures have economic consequences for the sustainability of local businesses and the state of local high streets and may disproportionately affect demographic groups such as the elderly, those on low incomes, and those experiencing poor public transport and digital broadband connectivity. Geographical modelling can help to examine and better understand the impacts of bank closures, inform and guide future reductions, and contribute to impact assessment exercises. Many recent studies concerned with the spatial provision of services have adopted Floating Catchment Area techniques, exploring their use in a wide range of thematic and geographical contexts, but hitherto not to retail banking. This study documents the trialling of several approaches to the implementation of variable sized catchments within FCA tools in order to address previous concerns regarding the use of a fixed size catchment in study areas that encompass a wide range of settlement types. Findings suggest considerable potential in applying these tools to the banking sector, whilst also drawing attention to current limitations in the type of data available to differentiate settlement areas and guide parameter settings. However, with the future inclusion of supply-side measures such as branch opening hours and the incorporation of multi-modal travel, FCA tools can enhance existing impact assessment exercises and provide the public with greater confidence that the implications of bank branch closures have been fully considered.

Keywords: Floating Catchment Area Techniques; Bank branch closures; Variable catchments; Spatial Analysis

1. Introduction

Recent enquiries and committee findings from both the UK Parliament and the devolved institutions in Scotland and Wales have drawn attention to the economic consequences of bank branch closures from both public and business perspectives (The Scottish Parliament Economy, Jobs and Fair Work Committee, 2018; National Assembly for Wales Economy, Infrastructure and Skills Committee, 2019). Evidence provided to these enquiries demonstrate that branch closures disproportionately impact groups such as the elderly and those on low incomes who are likely to be most dependent on physical banking facilities for services such as cash deposits or withdrawal. They also highlight wider community-wide economic impacts on the sustainability of local businesses, the state of local high streets and tourism opportunities in affected areas (see Access to Cash Review, 2019). Similar trends in bank closures have been observed in other countries, with general changes in consumer behaviour as well as factors unique to particular international contexts being cited as potential explanatory factors influencing variations in accessibility to financial services in countries such as Spain which has the highest per capita number of banks in the Eurozone (Martin-Oliver, 2019). This has led some US-based researchers in particular to point to the emergence of so-called cash or banking *deserts*, emotive terms which suggest that the wider needs of consumers are being overlooked, effectively leaving communities without access to either a branch, an ATM, or an alternative provider of banking services (Hegerty, 2016, 2020; Kashian et al., 2018). This, it is argued, can be compounded for those living in rural areas who often experience a combination of poor broadband service, inferior levels of public transport provision, and an increased likelihood of being charged for withdrawing money from remaining ATMs.

Whilst there have been waves of bank closures and reductions in the opening hours of the remaining branches since at least the late 1980s, recent moves to online and mobile-app banking with its consequent impacts on the numbers of financial transactions and customers passing through physical branches, has meant that the period since 2010 has witnessed some of the most dramatic reductions in provision (House of Commons Library, 2018). For example, drawing on the Experian Shop*Point dataset, a recent Financial Conduct Authority report (December 2018) estimated that banks in the UK closed 3,114 branches or around 24% of the network in the period 2012-2017, citing a 42% fall in the number of branch interactions between 2011 and 2016 as the primary reason for this decline. Losses have been experienced across the UK; in Scotland 368 branches closed between 2013 and 2018 (The Scottish Parliament Economy, Jobs and Fair Work Committee, 2018), whilst in Wales 235 closed in the period 2015 to 2018 (Which?, 2019). Written evidence provided by Which? to the UK Parliaments' Scottish Affairs Committee *Access to Financial Services in Scotland* inquiry suggests one in five (19%) of the population now live more than three kilometres from their nearest bank branch in the UK, and one in ten (8%) more than five kilometres. Such closures have wider implications for digitally excluded groups living in communities where there are few, if any, alternative financial providers and who are often amongst those most reliant on access to cash or cheques.

The UK-wide *Access to Banking Protocol* (renamed the *Access to Banking Standard* in May 2017), agreed to by major retail banks in 2015 and monitored by a self-regulatory body, the Lending Standards Board (LSB), provides guidance for banks planning closure programmes. It addresses issues such as customer notification, the publication of an Impact Assessment outlining the reasons for the planned branch closure, and the need to make customers aware of alternative assistance and help with their banking demands. Impact assessments can include data on the nearest post office with financial services, raise awareness of local broadband provision, and provide information on how far customers would need to travel following the closure of the branch under consideration. Rather than consult customers prior to the announcement of the closure, the standard applies when the decision to close the branch has already been taken and primarily aims to communicate the rationale for the closure or reduced opening hours of the branch, and signpost alternatives (such as post offices or mobile vans) to people in affected communities to potentially help lessen its impact (House of Commons Scottish Affairs Committee, 2018).

As part of this Standard, banks should demonstrate how factors such as the demographic characteristics of their customer base, the availability of remaining banking services and cash withdrawal facilities (post offices, ATMs, mobile branches) and the current state of public transport opportunities to access such alternatives have influenced their decisions. Although the regulatory body has no powers to reverse the commercial decision of a bank to close a branch, it can review through so-called thematic reports the type of information provided to customers informing them of closure. In this paper, we draw attention to the types of spatial analytical tools that have the potential to be incorporated into impact assessments to inform the public of the implications of proposed changes in provision. In doing so the aim is to draw on GIS-based analysis to better understand the potential implications for geographic patterns of accessibility prior to deciding to close or reduce the opening hours of a branch within a community.

Several studies have demonstrated how spatial analytical approaches can be used to investigate the implications of previous rounds of branch rationalisation, or more generally have shown how they may be used in the planning of banking services; these are summarised in Section 2 of this paper. In Section 3, we briefly review the background and development of floating catchment area (FCA) metrics, which are a group of analytical tools based on a modified gravity model that aim to quantify spatial accessibility by considering simultaneously both the availability of a service (the local supply-to-demand balance or density of provision) and characteristics of its proximity according to realistic network distances. In Section 4 of the paper, methods to adapt FCA tools in order to provide more insights into the implications of changes in banking services are described. The results of applying such accessibility models are presented in Section 5, which includes a discussion of their appropriateness in wider contexts and ideas for taking this research forward. Finally, we re-iterate the potential use of spatial analytical tools, in a period of continual rationalisation and change in the provision of both public and private services, for monitoring the implications on those most dependent on these facilities.

2. Literature Review: Spatial Approaches to Analysing Changes in Banking Provision

Previous studies of the impacts of variations in access to financial systems including banking services have highlighted the role of geography in a range of national and international contexts (see for example Alamá et al., 2015; Birkin and Clarke, 1998; Chakravarty, 2006; Leyshon and Thrift, 1995; Pollard, 1996). As evident from recent debates concerning the definition and empirical representation of the term *banking desert*, a variety of approaches have been used in studies concerned with examining the implications of changes in banking services. The Financial Conduct Authority (2018a), for example, used coverage on a district-level per capita basis (number of branches per 100,000 inhabitants in each local authority) as a proxy for access to branches to analyse changes over time in the UK (2012-2017). Their findings suggested a concentration of branches in busier retail areas from a previously more regionally dispersed coverage, but also suggested that those with a smaller percentage of their population living in rural areas were comparatively protected in terms of the losses experienced over this time period. The report recognised that travel distance to branches also plays an important role and analysis highlighted the increasing distances needed to reach the nearest branch following a closure which especially impacts those living in rural areas. Their findings, based on customer data and travel distances derived from OpenStreetMap, suggested that between 2015 and 2016, 9.1% of those banking in rural areas and 6.8% of those in urban areas were affected by branch closure. This led to a median increase in distance for consumers travelling to their nearest branch of 3.7 and 1.9 miles respectively (Financial Conducts Authority, 2018b).

Geographical modelling approaches have been used to examine the impacts of previous waves of closures of branches run by some of the largest banks and building societies in Britain (Leyshon et al., 2008). This study demonstrated how closures in the period 1995-2003 were spatially uneven and tended to be disproportionately concentrated in urban deprived areas (as measured by the English Index of Multiple Deprivation); a trend that continued until 2012 (French et al., 2013). Similar approaches have been used to study the implications of branch location patterns in other countries as part of wider studies of financial exclusion at municipality or neighbourhood levels (Alama and Tortosa-Ausina, 2012; Dunham and Foster, 2015; Pollard, 1996). Hegerty (2016) used buffer and spatial clustering approaches to analyse spatial variations in banks and credit unions (as of January 2015) at the block group level for two US cities. Specifically, one-mile buffers were generated from block group centroids and the number of facilities aggregated for each block as one strand and compared to a *hot-spot* measure (G* statistic) based on the numbers of banks/credit unions located in each block. These in turn were used in a regression analysis as part of a wider study of area-level demographic and economic characteristics associated with financial provision. Similar techniques have also been used to examine bank locations in relation to demographic characteristics at the block level for the city of Chicago in 2018 (Hegerty, 2020). This analysis found that areas with poorer access tended to be more deprived and less white than city-wide averages and showed that these trends have been relatively stable since the 2008 financial crisis.

Spatial approaches have also been used to study changes in accessibility to banks over time in the aftermath of specific closure programs or periods of prolonged decline. Argent and Rolley (2000), for example, drew on secondary data sources at five temporal cross sections to show that rural areas of New South Wales, Australia experienced a larger decline in bank branches in the period 1981-1998 despite witnessing population growth in the same period. Spatial analytical tools have also been used in decision-making processes regarding which branch(s) to close and for measuring potentially associated impacts. Morrison and O'Brien (2001) used spatial interaction models to examine the impact of a closure program of branches in the Wellington region of New Zealand which included estimating financial exclusion effects under different scenarios. More recently, Tischer et al. (2019) used detailed GIS mapping of financial infrastructure to show inequalities in access to cash in an urban area of the UK (Bristol) by generating 500m buffers around population weighted centroids and aggregating the different types of infrastructure present within these areas. They further demonstrated how such techniques can be used to examine those parts of the city that experienced the largest percentage loss of ATMs in the previous year.

Various alternative approaches have been used to measure potential accessibility or availability of banks in studies of overall financial provision at a range of spatial scales. Simpson and Buckland (2016) adopted a *container* approach to aggregate the locations of financial institutions for census tracts in Toronto, Canada for a range of temporal cross-sections over the period 1981-2006. They explored changes in the patterns of provision across the city over time, as well as potential associations with demographic variables such as income at the tract level. Others have focussed on using *proximity* to examine spatial patterns. Martin-Oliver (2019) for example used bank branch locations in Spain (2007–2014) to examine changes in straight-line distances between branches as a proxy for accessibility. When averaged across municipalities for two cross sections they found poorer accessibility in municipalities with lower populations. Distance-based variables were also adopted by Kashian et al. (2018) using as the definition of *bank deserts* those five percent of census tracts in the USA in 2009 and 2015 that were the greatest distance from the tract centroid and the nearest bank office location weighted by population. Variations in access were analysed with census data to examine potential association with socio-demographic data at each cross-section to identify areas with lower levels of provision. However, Leyshon et al (2008) illustrated potential problems in using straight-line distances when assessing changes in banking provision, using a case study of a community in the South Wales valleys which lost a bank branch in the early 2000s. Failure to take into account the intervening topography, road network, and lack of public transport opportunities when identifying the nearest alternative service for the community resulted in an unrealistic appraisal of the accessibility implications of the loss of provision. This contradiction between straight-line and actual travel distance had implications for those areas officially defined as *financially excluded* (based on the voluntary Banking Code in place at the time; defined as when the nearest alternative bank branch is more than one mile (urban) or four miles (rural) distance by road (French et al., 2008)).

This study aims to address some of the limitations identified above, firstly by using enhanced two-step floating catchment area (E2SFCA) techniques. FCA-metrics are a set of spatial analytical techniques widely adopted in recent research literature concerned with the spatial provision of services. Initially developed in the context of examining access to primary health care facilities, the simple interpretability of their outputs and ease of computation within a GIS have led to their subsequent adoption in application areas as diverse as access to public libraries (Guo et al., 2017), early-years childcare facilities (Langford et al., 2019), emergency services (Kiran et al, 2020) and greenspace (Xing et al., 2020). FCA-metrics return a supply-to-demand score based on localised travel-catchments and potentially allow more nuanced insights into accessibility than can be derived from simple proximity alone, at finer spatial scales than is typically possible from container-based approaches. In this study E2SFCA models are used to generate a comprehensive and systematic country-wide mapping of the localized supply-demand balance in bank branch provision. Such information is invaluable to those charged with strategic decision making and policy development, providing a synoptic overview of the level of provision experienced at the local level. The ability to repeat such analyses across time frames, or to feed in alternative models of future infrastructure provision, offers a powerful mechanism to monitor, evaluate and manage a volatile and rapidly changing, but nevertheless economically important, service provision.

Furthermore, the study aims to show that the same actions required to drive E2SFCA models, specifically network-distance tracing between service provision points and population demand centres, can also yield detailed insight into the potential vulnerabilities of local communities faced with specific individual branch closures. Thus a spatial analysis undertaken primarily to provide strategic overview of geographical patterns in service provision can be further leveraged to deliver the sort of information needed to support and inform the Impact Assessment exercises discussed earlier that are required when potential bank closures are under consideration.

3. Floating Catchment Area (FCA) based approaches

3.1 Introduction

Two-step floating catchment area (2SFCA) methodology has developed and been reported through a series of seminal academic papers, to which the reader is directed for further details

(Radke and Mu, 2000; Luo and Wang, 2003; Wang and Luo 2005). Fundamental to its calculation are travel catchments, based on time or distance, constructed around both service supply points and population demand centres present in the chosen study area. In summary, in step 1 the potential demand population, P_{kj}, acting on each service provider point j is established by determining the total population that falls inside a catchment area k_j computed around it, as defined by the local transport network and a maximum travel time/distance *dmax*. Dividing the supply capacity S present at point j by this local demand population yields an estimate of its availability, R_j, which is the supply-to-demand ratio S_j / P_{kj}. In step 2, a catchment area k_i is similarly computed around each population demand centre i, again defined by the local transport network and maximum travel time/distance *dmax*. The value of all R_j scores falling inside each catchment k_i are summed to yield a final accessibility score A_i for demand point i. In the enhanced two-step floating catchment area (E2SFCA) algorithm, introduced by Luo and Qi (2009), additional distance-decay terms W_j and W_i are applied in each step to account for the effects of geographical friction. They model the declining degree of interaction expected between supply and demand centres in response to their increasing separation, in the same manner as in classic geographical gravity models, of which E2SFCA is a variant. However, the most appropriate form of distance decay function to adopt in either E2SFCA or geographical gravity models remains an area of considerable contention and debate (see for example, Chen and Jia, 2019; Bauer and Groneberg, 2016).

The output from two-step FCA models are geographically weighted supply-to-demand ratios based on the likely activity spaces of the service users. Scores represent the proportion, or share, of the total service supply capacity consumed by (or allocated to) each demand centre. This, arguably, is one reason why E2SFCA studies have appeared with increasing frequency in geographical research literature over the last two decades. Planners and social scientists are already familiar with accessibility reported as a supply-to-demand ratio pertaining to a pre-defined geographical region (e.g. a County, Parliamentary Constituency, or Census block). The outputs of E2SFCA models are thus more intuitive and better understood by professionals, and the wider public, than those returned by traditional gravity models.

Defining and justifying the value of *dmax* which controls the floating catchment size has, however, often proved to be problematic. Each catchment represents the maximum distance/time customers are willing or able to spend in order to service their needs. Despite inherent difficulties in identifying this limit, which is the subject of much of this paper, the fundamental concept of a finite travel tolerance remains intuitive and appealing. For example, if it is accepted that a rational individual would not consider using a bank that requires a 10 hour round-trip by car, it follows that a finite limit to their travel tolerance must exist no matter how difficult it may be to define. The philosophical standpoint of finite travel limits is inherent in all two-step floating catchment area methodologies and this may be another reason why they have often been preferred to traditional gravity models in recent years.

3.2 Variable FCA approaches

A relatively recent focus in E2SFCA literature has been on examining the impact of adopting variable sized catchment areas, with several studies drawing attention to alternative approaches to estimating variable catchment sizes. The study by Luo and Whippo (2012) was one of the first to draw attention to the limitations of fixed size catchments, proposing instead that they be incrementally enlarged until a minimum specified supply-to-demand ratio is attained. A similar approach was taken by Naylor et al. (2019) to provide a national picture of access to health care providers in the United States. Variable 2SFCA methods, it is suggested, better reflect the proposition that residents of rural areas are willing to travel further and spend more time travelling to avail themselves of services (McGrail and Humphreys, 2009). The population base and ratio were used to determine travel time catchment sizes for individual locations in a continuum of urban to rural settings (proxied by population density) and to calculate accessibility in the FCA models. This it was suggested “revealed greater detail in spatial variation of accessibility compared to results using fixed catchment sizes” (Luo and Whippo, 2012; p.789); with fixed catchment sizes observed to overestimate accessibility compared to a variable catchment model. However, as has also been recognised that whilst conceptually this may be a suitable approach for measuring access to health services, the lack of evidence with which to determine an optimal ratio when applying it to other thematic studies (such as banks in this instance) limits the potential application of this methodology (Wang, 2012).

It remains that case that, to date, most research on variable catchment 2SFCA has been concerned with applying such tools to measure access to health care, and primary health care in particular (McGrail, 2012). In one study McGrail and Humphreys (2009) suggested population catchments could be defined based on the area covered by the nearest 100 services (up to maximum travel time of 60 minutes). In a later study McGrail and Humphreys (2014) propose an alternative for defining variable catchments by initially using a *five-level dynamic* *catchment size* (set to 30, 45, 70, 120, and 200 minutes) to reflect the range of circumstances encountered in rural areas of Australia and as a response to varying health service utilisation behaviours in each setting. By adopting five levels of national remoteness for the population demand centres, as defined by the Australian Bureau of Statistics, breakpoints were defined and used to construct varying catchment sizes, with the results being compared to that obtained from a uniform catchment size of 60 minutes. A detailed investigation of specific scenarios found anomalies that illustrated the potential limitations of setting catchment size according only to the remoteness typology. This in turn led to an alternative solution that further refined catchment sizes based on proximity of the population at the catchment boundary to services in areas that shared either the same or differing remoteness levels. Along with further ground rules the adjusted travel time limits for each category of remoteness were, in the authors' view, a better reflection of expected travel behaviour. This example illustrates the complexities faced by those attempting to use dynamic catchment sizes, often in the absence of any empirical evidence on actual service utilisation behaviour, and opens this up as a research area for further exploration and application.

4. Data and Methods

4.1 Resources

The provision of retail bank branches across Wales was modelled using data derived from the Points of Interest Great Britain business listings (Ordnance Survey, 2018a). This is a database of over 4 million records containing information relating to businesses, public infrastructure and government authorities across the UK. Each listed feature is provided with a UK national grid coordinate and is classified into one of nine major groups, including *commercial services* from which our data were drawn. From a dataset dated March 2019 a subset of features was extracted containing all points falling inside the national boundaries of Wales and relating specifically to retail bank branches. A total of 413 sites were thus identified, belonging to 11 commercial brands (Figure 1). The branches of distinct brands sometimes had an identical postcode and these appear co-located on this map, but all are treated as separate entities during the analyses. Unfortunately, this data source did not provide any meaningful supply-side estimate of service capacity or quality (such as branch opening hours, or the number of service counters available) so all sites were assumed to be of equal status. However, the E2SFCA methodology can readily incorporate such information into the analysis if it were to become available at some future date.

[INSERT FIGURE 1 ABOUT HERE]

The potential demand for banking services was derived from population counts associated with 10,036 Output Area (OA) population-weighted centroids in Wales, as used to disseminate UK Census of Population statistics. Each point had an associated mid-year population estimate, dated 30th June 2018, from which a count of all persons aged 16 and above and resident in the associated OA polygon was derived. Combining the total of 2,575,922 such persons across Wales with the number of bank branches, yielded a global supply-to-demand ratio of 0.16 branches per 1000 adult population. Both point datasets were snapped to a topological road network derived from OS Open Roads data (Ordnance Survey, 2018b). Each point was displaced to be directly on a road segment at the closest possible perpendicular distance. With a nominal scale of 1:25000 this dataset provided a comprehensive topologically connected representation of all major and minor roads in Wales.

All data were loaded, stored, managed and analysed in a PostgreSQL (2017) database installed with PostGIS (2018) and pgRouting (2018) spatial extensions. Enhanced Two-Step Floating Catchment Area (E2SFCA) statistics were computed using a bespoke suite of software written in C#. This allowed for the specification of the modelling parameters before leveraging the spatial querying, spatial indexing, and network routing capabilities of PostGIS/pgRouting to aid in the computation of E2SFCA accessibility scores.

4.2 Methods

The computational process involved the execution of various E2SFCA models, all using a linear distance-decay function, and progressing through three main stages: the first used fixed-sized floating catchments; the second used catchments sizes that were varied in accordance with a rural/urban classification of the OA centroids; the third used catchments sizes that were varied in accordance with the proximity of bank branches to each OA centroid. Each approach is described in more detail in the following sections.

4.2.1 ***Fixed-size catchments***

Our first analyses explored outcomes from E2FSCA models using a fixed catchment size, set according to estimated average travel distances reported by the Financial Conduct Authority (2018b). These values were computed from a random sample of adult customers drawn from a database of 1.5m entries that linked a home address to a current account held with a major UK retail bank. Travel distance was measured via an OpenStreetMap network to the nearest branch of the specific brand used by the customer, and will therefore tend to over-estimate the distance to the nearest branch of any provider. In December 2016 consumers in the UK travelled on average 4.2 km to reach their nearest branch. This was further differentiated into 8.2 km in rural areas and 3.1 km in urban areas. Using this information, E2SFCA models were computed first with a fixed catchment size of 3.1 km, and then with a fixed catchment size of 8.2 km.

4.2.2 Variable catchments (categorised)

A logical development of the standard E2SFCA methodology is to allow demand catchments to vary in size between different environments (McGrail, 2012). This inevitably raises questions concerning the basis upon which these environments are differentiated and how their respective catchment sizes are determined. The average urban and rural travel distance to nearest branch quoted above supports the hypothesis that urban dwellers expect to travel shorter distances than their rural counterparts when seeking access to a bank. An E2SFCA model that incorporates this distinction would appear therefore to be a desirable option. The urban and rural distances reported by the Financial Conduct Authority (2018b) were based upon the 2011 Rural-Urban Classification for Small Area Geographies dataset (henceforth RUC2011, Office for National Statistics, n.d.), which provides a consistent and well-documented identification of the rural/urban status of all UK Output Areas. Using the same RUC2011 classification, an E2SFCA model was computed in which OA demand catchment sizes were set as either 3.1 km or 8.2 km respectively, according to this code.

The RUC2011 dataset further differentiates four urban and six rural sub-categories (Table 1). Only eight of these classes are present in Wales, but nevertheless present an opportunity to apply a finer level of environmental partitioning than the rural/urban division alone.

[INSERT TABLE 1 ABOUT HERE]

To operationalise this approach the network distance of the nearest bank branch to each OA centroid was computed according to its full RUC2011 classification. An initial appraisal of these data suggested strong overlaps between some RUC2011 groups, leading to the adoption of a five-class scheme documented in Table 2. Although the average network distance to nearest branch varied greatly according to the relative rurality of each category, it did not offer a sound basis on which to define catchment sizes because of the non-symmetrical distribution of distance values in each class (all had positive skewness ranging from moderate to high). To account for this the 95th percentile distance in each class was adopted as its catchment size before a second variable catchment E2SFCA model was computed based on the five-class scheme.

[INSERT TABLE 2 ABOUT HERE]

4.2.3 Variable catchments (adaptive)

This stage of the E2SFCA analysis sought to utilise the concept of variable catchments whilst avoiding the need to group OAs into categories. Instead, the travel tolerance of residents in each OA was adapted uniquely to their specific environmental circumstances. The logic behind this approach is that OA residents will ultimately travel as far as is necessary in order to reach a bank. The spatial database was thus used to compute for each OA the network distance to the N^{th} nearest branch, where N ranged from 1 to 6. When N=1, this defines that the catchment size of each OA be just large enough to encapsulate its nearest branch. Given 10,036 population centres and only 413 branches in the dataset many OAs must still share the same nearest branch, implying that a supply-to-demand ratio as computed by E2SFCA is still of relevance. Furthermore, the full set of computed network distances to the nearest N branches are themselves potentially useful information for studying the vulnerability of specific OAs to potential future closures, as is discussed later.

Clearly, the nearest branch will not always belong to the bank used by particular residents of an OA. Furthermore, many other reasons may exist for choosing not to utilise the nearest branch, such as opting for one conveniently located in respect to a workplace, one that falls on-route to friends and relatives, or one pertaining to a particular brand. Rational individuals might be expected to seek banking services broadly within their local neighbourhood, but do not necessarily always use the nearest branch. By relaxing the rule on catchment size to use the distance to the Nth nearest branch, where $N > 1$, we can potentially accommodate such behavioural patterns into the modelling process. Thus, a series of E2SFCA scores were computed using adaptive catchment sizes based on network distance to the Nth nearest branch. Values of N from 1 to 6 were adopted in order to assess the potential of this approach and to explore the sensitivity of outcomes to the rank selected. The essential feature of these experiments is that each demand centre has a unique catchment size defined by its network-based proximity to branches within its local vicinity.

Adaptive demand catchments have been explored before when analysing access to primary health care services; for example, McGrail and Humphreys (2014), and Lou and Whippo (2012). In the former study catchment size was constrained to a maximum number of 100 service delivery points and a further rule limited them to a maximum 60 minutes travel time. In the latter, an initial size of 10 minutes travel time was set before incrementally increasing this until either a time limit of 60 minutes was reached, or a minimum supply-to-demand ratio was attained within the catchment. Our methodology has similarities with both approaches. Like Lou and Whippo (2012) our catchment sizes increase until a condition is met; but in the banking scenario no appropriate target supply-to-demand ratio exists. So instead, our size is adjusted with the objective of achieving a minimal level of choice. Like McGrail and Humphreys (2014) our catchment sizes are constrained to a maximum number of service delivery points. However, their target of 100 service delivery points is clearly inappropriate in the context of bank branch provision, so we adopt very much smaller numbers. Despite such differences, all three approaches remain alike in that all attempt to better model the behaviour of individuals seeking a service from within their local neighbourhood.

5. Results

Due to a lack of empirical evidence with which to judge the relative merits of alternative models, researchers have often been forced to rely upon visual analysis and their local knowledge and expert opinion when assessing the outputs from experimental 2SFCA approaches (McGrail and Humphreys, 2014). In the following sections we attempt to interpret the results obtained from trialling different approaches to E2SFCA modelling with variable-sized catchments by comparing their outputs to those derived from a single fixed-size catchment. It should be noted that all data used in the experiments were constrained to the limits of Wales. Consequently, boundary effects may arise along the eastern border with England due to the fact that potential interactions between population demand centres and bank branches located either side of this border have not been accounted for. Our discussion and examples focus only on areas that fall beyond the region where border effects might occur.

5.1 Single fixed-size catchments

Using a 3.1 km fixed size catchment, almost 37% (3,697) of OAs returned *no access*, indicating that residents in these population centres would be unable to reach a branch within this distance. Almost exactly two-thirds of OAs in Wales are classified as urban, one third as rural, according to the RUC2011 scheme. Amongst rural OAs almost three-quarters returned *no access* and although this figure declined in urban OAs it still amounted to almost one fifth of all instances (Table 3). A map of E2SFCA scores based on this catchment size provided good differentiation of accessibility inside major urban areas, such as Cardiff, but in rural areas it was too small to be useful; many communities were unable to reach a bank given a travel limit of 3.2 km, leading to a predominance of *no access* outcomes in most of rural Wales (Figure 2);.

[INSERT TABLE 3 ABOUT HERE]

[INSERT FIGURE 2 ABOUT HERE]

A simple way to eliminate *no access* scores is to increase the floating catchment size. Raising the travel limit to 8.2 km resulted in less than 0.25% of urban OAs returning *no access*, although 28% of rural OAs continued to do so. Thus even this larger catchment size could not accommodate the most rural regions of Wales, despite being guided by empirical evidence suggesting this is how far rural residents travel on average to reach their actual bank across the UK as a whole. Furthermore, these larger catchments were now unrealistic for urban dwellers, who could reach almost every branch in the metropolitan area at this setting. Consequently, although the map produced by this model showed more OAs with an E2SFCA score, in urban centres such as Cardiff they resulted in over-generalised patterns. Previous studies have reported that using a single fixed-size catchment is problematic in regions that encompass a wide range of population densities (McGrail and Humphreys, 2012). This study corroborates the opinion that E2SFCA scores based on a single fixed catchment size are unsatisfactory in geographical settings that contain a wide range of environments from deeply rural through to highly urban. A small catchment size yields valuable information on accessibility levels in urban areas but it leaves rural areas without a score, whilst the large catchment size needed to return meaningful scores in rural areas renders the output in urban areas as uninformative.

5.2 Variable catchments (categorised)

Using variable catchments determined by the RUC2011 classification produced, on balance, an improved accessibility map. The rural/urban split resulted in better overall coverage (fewer *no access* scores) than that achieved with a single 3.2 km catchment, whilst simultaneously retaining the urban differentiation that was lost when a single 8.2 km catchment was deployed. However, close inspection revealed a number of problems were still present. First, as noted previously, the travel limit of 8.2 km is insufficient to model the activity space of most rural residents, so the prevalence of *no access* outcomes in rural areas remained. Adopting a larger catchment size might rectify this problem, but it would be preferable to specify this using alternative evidence rather than relying on an arbitrary decision.

[INSERT TABLE 4 ABOUT HERE]

By design all UK Output Areas contain a similar population count (around 300 persons) and are therefore smaller in urban areas and larger in rural areas. Welsh OAs classified as urban have an average area of 0.25 km^2 (range 0.005 to 23.3), while in rural OAs this increases to 5.74 km^2 (range 0.018 to 137.6). However, because OAs are represented by their population-weighted centroids in the E2SFCA models, the distance of its neighbours and their respective classifications might provide better insight into how the catchments assigned to each class potentially interact, and so provide some guidance and justification for a manually assigned size. Using the spatial database the network distance and RUC2011 codes of the nearest neighbours of each OA centroid were extracted, as summarised in Table 4. This analysis indicated that the closest centroid to each urban OA was almost without exception (6701 times in 6709) another urban OA, on average 187 m apart. Similarly, the closest OA to each rural OA was almost always (3223 times in 3327) also rural, on average 709 m apart. This illustrates both the clustered nature of OAs in each category and their aforementioned sizes. Of greater interest perhaps are the network distances to the nearest OA not of the same RUC2011 code, because this provides some evidence regarding how clusters may interact with each other spatially. For urban OAs the average network distance to its nearest rural OA was 2520 m, and for rural OAs to its nearest urban OA this averaged 10922 m. These numbers suggests the 3.1 km catchment size assigned to urban OAs could be a little too large causing them to interact with rural populations in places where the respective clusters spatially abut. They also suggest it may be possible to increase the 8.2 km catchment size for rural OAs to provide a better analysis of the deeply rural environments without causing detrimental effects.

However, the mapped accessibility scores also revealed instances where some OAs received E2SFCA scores while their close neighbours did not; which was difficult to justify or explain based on local knowledge of the study area. The problem was particularly prevalent in the South Wales Valleys region, where many adjacent towns and villages displayed this trend although all were similar post-industrial conurbations in a peri-urban environment. Comparable "perverse outcomes" were reported by McGrail and Humphreys (2014) in a national study of access to general practitioners in Australia using a similar system of categorised catchment sizes. They attributed its primary cause to large differences in catchment sizes between classes, which may be a contributory factor here too, although the analysis of network distances to nearest neighbours amongst rural and urban OAs also suggested another possibility.

Displayed in Figure 3, these suggest there was little true differentiation between RUC2011 classes. Although rural OAs sometimes had a more distant nearest neighbour, in many instances they were as closely spaced as their urban counterparts. The same issue is illustrated in map form in Figure 4. In a deeply rural setting (area A) the centroids are widely spaced and would benefit from a large catchment size (greater than the current 8.2 km) to return meaningful E2SFCA scores. In a city environment (area C) the centroids are closely packed and the current 3.1 km catchment size is appropriate. In the South Wales Valleys (area B) both urban and rural classifications are interwoven amongst the towns and villages. Many of those identified as rural were just as closely packed as others defined to be urban. It was this inconsistent classification combined with the varying catchment sizes assigned to each class that led to the questionable patterns in accessibility scores produced by the model in this environment. Unfortunately, this also means that while setting a larger rural catchment size might be beneficial for deeply rural OAs, it is likely to lead to further problems and inconsistencies arising within this challenging environment.

[INSERT FIGURE 3 ABOUT HERE]

[INSERT FIGURE 4 ABOUT HERE]

This problem can potentially be addressed by adopting a more detailed OA classification scheme. A similar solution was pursued by McGrail and Humphreys, who added additional rules to define three further sub-categories to an initial five-class scheme, which thereafter improved the outcome. By replacing the urban / rural distinction with the more detailed five-class scheme, each with a separate catchment size defined as described earlier in Section 4.2.2, it may be possible to disentangle these settlement environments and fine-tune their respective catchments to better reflect the true travel behaviour of residents within each group. Unfortunately, visual analysis of the output suggested that results remained disappointing. Once again inconsistent and seemingly unjustifiable differences arose amongst accessibility scores reported from adjacent communities, and between distance settlements that appeared themselves to be broadly similar in nature. Amongst these anomalies was another situation previously reported by McGrail and Humpherys (2014), whereby settlements falling roughly midway between others and devoid of banks themselves would returned higher scores than adjacent towns that actually contained a branch. Analysing the network distance to nearest bank in each category showed, once again, that despite the increased number of classes the issue of poor inter-class differentiation remained (Figure 5).

[INSERT FIGURE 5 ABOUT HERE]

The problems encountered in both the two-class and five-class models had the same fundamental cause; namely that the RUC2011 classification was inadequate for differentiating residential banking environments. Despite its status as a definitive UK National dataset for rural/urban differentiation, it was not designed specifically for this purpose and its classes were ineffective in defining clear divisions in the banking environments experienced amongst the range of settlements encountered within this study area.

5.3 Variable catchments (adaptive)

Outcomes derived from adaptive variable catchments displayed several notable differences to those reported above. Firstly, because these catchments always included at least one bank branch, all OAs return an E2SFCA score. When N = 1 each OA is effectively assigned to use only its nearest branch, which has the effect of clustering OAs into groups that share the same nearest branch. This caused some problems to be manifested by bank branches that were located in tight clusters. One branch from the local cluster would typically prove to be nearest to most of the neighbouring OAs leaving others in the same cluster as being closest to only a few. This generated large disparities in the accessibility scores recorded by the surrounding OAs whereas, in reality, all would benefit equally from the presence of the cluster. Figure 6 illustrates an example, in which three distinct OA groups are created by the presence of three branches in a local cluster. The southern grouping is the largest, and consequently has the largest total population. This results in the branch with which they are associated returning a low availability score, and consequently these OAs receive low E2SFCA scores. Meanwhile

OAs in the eastern cluster report much higher E2SFCA scores primarily only because fewer of them are present in the cluster, thereby ensuring the availability of the bank to which they are closest is computed to be greater.

[INSERT FIGURE 6 ABOUT HERE]

It is also notable that with N=1 the distance-decay function has no effect because the applied weightings simply cancel each other out in each step of the calculation. With distance-decay ineffective, some rural OAs report high E2SFCA access scores primarily because their (not very) nearest branch serves only a small population total. Overall, the results from this model were problematic, mainly because they are driven only by the perceived demand placed on each supply point without any realist accountability of the local supply density. The issue is largely addressed when adaptive catchments are relaxed to include the N^{th} nearest branch with N = 2 or more. The local supply-to-demand balance resulting from clustered service points, and the effects of geographical friction modelled by the distance-decay function now operate in much the same way as they do for a traditional fixed catchment model.

With N set to more than one the E2SFCA scores appeared both informative and largely explicable. OAs positioned close to local clusters reported high accessibility scores. OAs in remote hamlets without a local branch reported low scores. Clear distance-decay effects were evident in the vicinity of service provision points. Most of the problematic situations identified previously with fixed size catchments and variable catchments based on an OAs classification were no longer evident. Based on our local knowledge, but nevertheless a subjective opinion, these models appeared to show the most convincing portrayal of access to bank services across all environments in the study area. Furthermore, examining the E2SFCA scores arising from varying the number of nearest branches (i.e. N = 2, 3, etc.) can provide further insight into the robustness of service accessibility experienced by particular communities. Mapping the change in accessibility score reported under differing scenarios helps to indicate which specific communities are most vulnerable to the effects of future branch closures in their vicinity. For example, many OAs whose E2SFCA scores declined greatly between N=2 and N=4 were located in the South Wales Valleys, suggesting that these areas could experience a notable decline in access to banking services if the branch network was further diminished. However, all interpretations must be performed carefully because, for example, areas shown to experience little change might still relate to a consistently poor baseline accessibility status.

While computing a series of E2SFCA adaptive catchment models, a detailed profile of each OA's proximity to its *N* nearest branches is captured within the database. As noted earlier, this presents an opportunity to also explore at very local level the potential implications of individual branch closures on specific communities. Whilst a map of E2SFCA scores drawn across the study area provides a synoptic view of patterns that may help to formulate strategic responses, this network-distance profile to *N* nearest branches can inform individual communities of the likely impacts of a branch closure, and would be valuable in formulating detailed Impact Assessment documentation. To illustrate this, a few case studies drawn from our database are presented in Table 5.

[INSERT TABLE 5 ABOUT HERE]

Case 1 is an OA located in the Cardiff that currently has access to 4 branches within approximately ½ km distance. Although choice would diminish, travel distance to the nearest branch would not be unduly affected by the loss of its nearest branch. Case 2 lies in a residential suburb of Cardiff and currently has access to two local branches at a similar ½ km distance. While the impact of one closure would be minimal, if both were to be lost the residents would face travelling much further, more than 3 km, to reach a bank. Case 3 lies at the city margin with a single nearby branch. Its access to banking is very vulnerable to the closure of this branch because the next nearest cluster is located at over 3.5km distance. A similar but more extreme example is the OA located in a Market Town. This is reliant on a single branch at just over ½ km distance. Its closure would force residents to face hugely increased travel distances of almost 20km. Case 5 is an OA in a relatively remote South Wales Valley without a local branch. All its immediate options involve relatively long travel distances already, and the situation would not change greatly if any of the nearest branches were lost. Finally, Case 6 is an OA in a rural hamlet that faces a predictably long journey to reach a bank. Nevertheless this could still increase by more than 50% if the nearest branch were closed.

6. Discussion and Conclusions

Recent enquiries into access to banking services in Scotland and Wales have suggested that more research is needed to assess current levels of provision of banking and financial services, including the free-to-use ATM network, in order to understand what is needed to maintain a universal banking provision. For example, the *Economy, Infrastructure and Skills Committee* of the National Assembly for Wales recommended in their October 2019 report (p. 7) the need to “map the gaps in banking services overall – access to banks, Post Offices, free-to-use ATMs and connectivity for digital banking” to inform future strategies aimed at improving the well-being of residents in communities most severely impacted by a loss of provision. At the same time, there have been concerns expressed in some quarters regarding the lack of opportunities for the public to have a meaningful input into the decision to close a branch. This in turn has drawn attention to the perceived ineffectiveness in this regard of the Access to Banking Standard and the role of impact assessments in consulting on the implications of bank closures or changes in opening hours within branches in order to help understand and mitigate the impact of closures on communities.

Our concerns in this paper relate to the impacts of changes in bank branch services on patterns of geographical accessibility and the potential for modelling approaches to be included in an overall assessment of the implications of such proposals prior to implementation Whilst acknowledging concerns regarding financial exclusion are broader than just those surrounding the impacts of geographic distance (see Midgely (2002) for example), we suggest that the type of research discussed in this paper can contribute to such debates by providing a baseline picture of current provision as well as helping to monitoring the future impacts of proposed changes. In particular, the types of sophisticated spatial analytical methods reported in this paper can generate insight and information to inform impact studies, direct closure plans and instigate plans to mitigate their effects. Furthermore, by encompassing access to a wider range of facilities that provide banking services (such as building societies, ATMs, credit unions, community banking models, mobile van delivery and post offices), as Table 5 illustrates, these tools could help examine the implications of such changes on a locality basis by providing a more comprehensive picture of the impacts of changing provision. Furthermore, such outputs have the potential to be included in wider studies of financial exclusion that compare patterns of accessibility to those of socio-economic variables such as age, disability/health and deprivation and consider local factors such as public transport provision.

Spatial analytical approaches to measuring access to banking services have largely adopted simple distance metrics to monitor the impacts of bank closures. At the same time, there is an increasing literature base which highlights the potential for approaches based around floating catchment area techniques that provide potentially more nuanced analyses of variations in access to a wide range of services. To our knowledge this is the first paper to apply such techniques to the study of banking provision. Our findings suggest there is real potential in adapting these tools for the banking sector by considering approaches that adopt variable catchment sizes to move beyond fixed catchment methods and help to assess the spatial accessibility implications of bank closures. By highlighting examples of the mapped (and tabular) outcomes of different approaches to estimating the parameters within such models this study also draws attention to the limitations of the type of datasets available to differentiate areas and guide the choice of such distance settings at detailed spatial scales. In reality, the approach taken is likely to be informed by expert judgement on the usefulness of these outputs under different types of modelling scenarios. However, this approach and the potential inclusion of other supply-side measures such as opening hours and range of banking services, as well as the incorporation of multi-modal travel within FCA calculations (Langford et al., 2016; Ma et al., 2019), offer real potential to incorporate E2SFCA tools as part of wider enhancements to existing impact assessment exercises that could provide the public with more confidence that the implications of such closure programs have been fully considered.

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This paper is based on Points of Interest [CSV geospatial] data Updated: March 2019. © Database Right/Copyright 2019. Using: EDINA Digimap Ordnance Survey Service, https://digimap.edina.ac.uk/, Downloaded: July 2018; OS Open Roads data set © Crown copyright and database right 2018.

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		Urban			Rural		
		Major Conurbation	Minor Conurbation	City and Town	Town and Fringe	Village	Hamlets & Isolated Dwellings
Sparse setting?	No	**A1** (not present)	**B1** (not present)	**C1**	**D1**	**E1**	**F1**
	Yes			**C2**	**D2**	**E2**	**F2**

Table 1: Rural / Urban classifications of UK Output Areas (RUC2011)

RUC2011 Code	Five-class grouping	Average network distance to the nearest bank	Skewness within class	Catchment size based on 95th percentile distance
C1	**G1**	2063 m	1.27	4650 m
C2	**G2**	1208 m	0.43	2500 m
D1	**G3**	4203 m	1.19	11000 m
D2				
E1	**G4**	6493 m	1.12	12200 m
F1				
E2	**G5**	9766 m	0.54	19000 m
F2				

Table 2: Distance to nearest bank and catchment sizes of a five-class OA classification scheme

	Urban	Rural
Total count	6709 (67%)	3327 (33%)
Catchment size	OAs reporting *no access*	
3.1 km	1271 (19%)	2427 (73%)
8.2 km	15 (0.22%)	937 (28%)

Table 3: Distribution of urban and rural OA classifications in Wales, and the proportions returning a *no access* outcome when using a fixed-sized catchment

RUC2011 classification	Distance to nearest rural OA	Distance to nearest urban OA
Urban	2520 m	187 m
Rural	709 m	10922 m

Table 4: Distance of OA centroid to nearest-neighbour according to RUC2011 classifications

	Urban (centre) C1	Urban (suburb) C1	Urban (fringe) C1	Market Town D2	South Wales Valley Town D1	Rural Hamlet F1
N = 1	534	393	173	560	6942	11471
2	568	440	3706	19589	8501	17518
3	597	3131	3765	19652	8542	17578
4	686	3148	3807	28805	8544	18866
5	3572	3362	8394	28852	8601	22291
6	3692	3493	8504	28911	10637	22355

Table 5: Distance profiles to N^{th} nearest bank for selected OA centroids

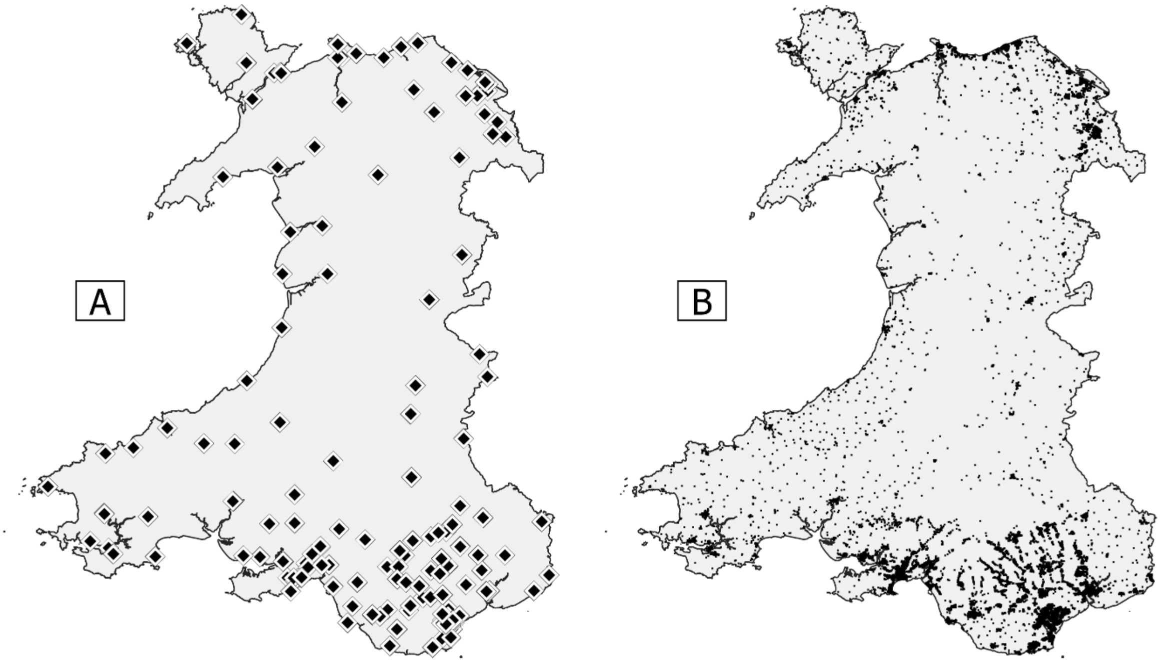

Figure 1: Distribution of bank branches (A), and OA population-weighted centroids (B)

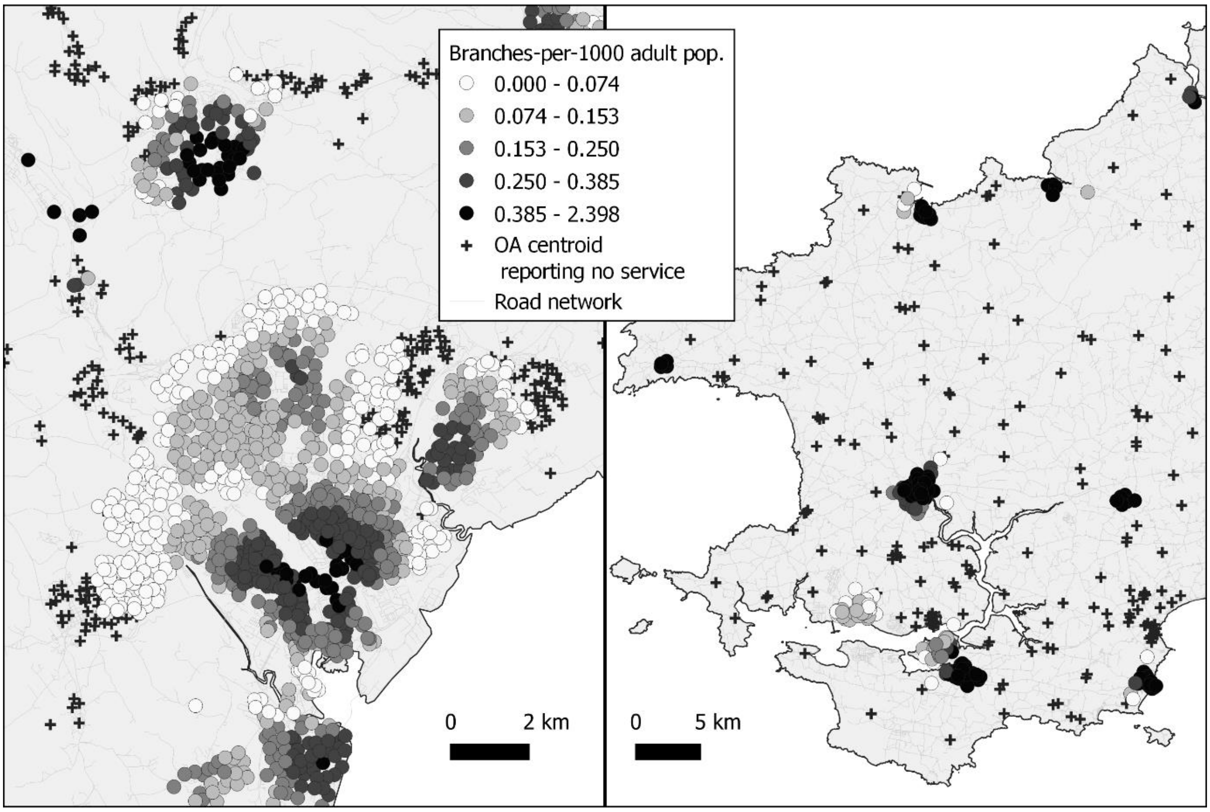

Figure 2: E2SFCA accessibility scores, for Cardiff city (left) and Pembrokeshire (right) based on a 3.1 km fixed-sized catchment and using a quintile classification scheme .

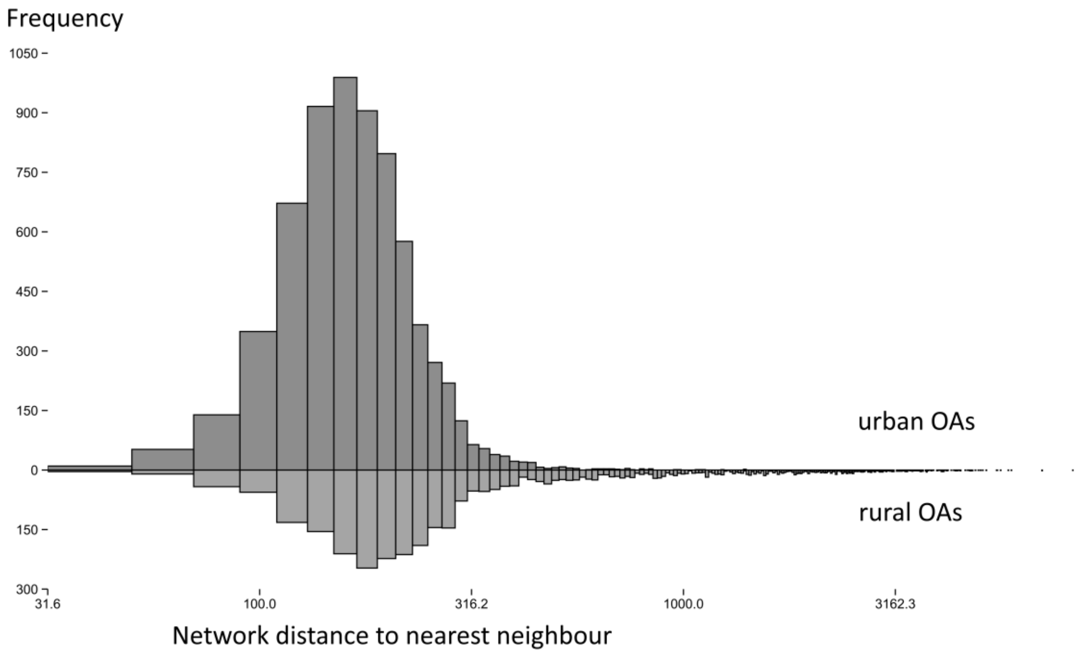

Figure 3: Network distance to nearest neighbour for urban (upper) and rural (lower) OAs

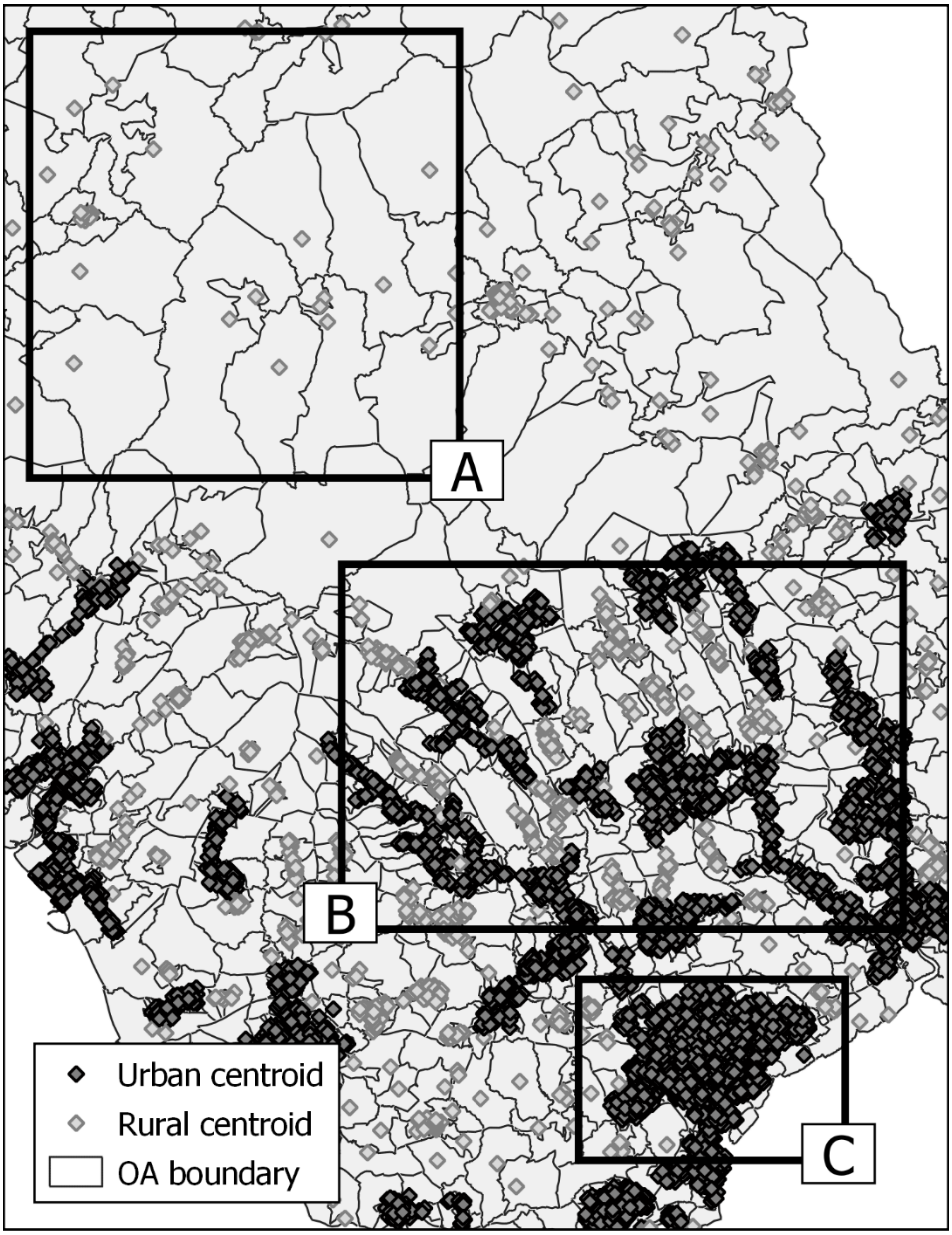

Figure 4: Distribution of urban and rural OA centroids in: rural Wales (A), the South Wales Valleys (B), and Cardiff city (C).

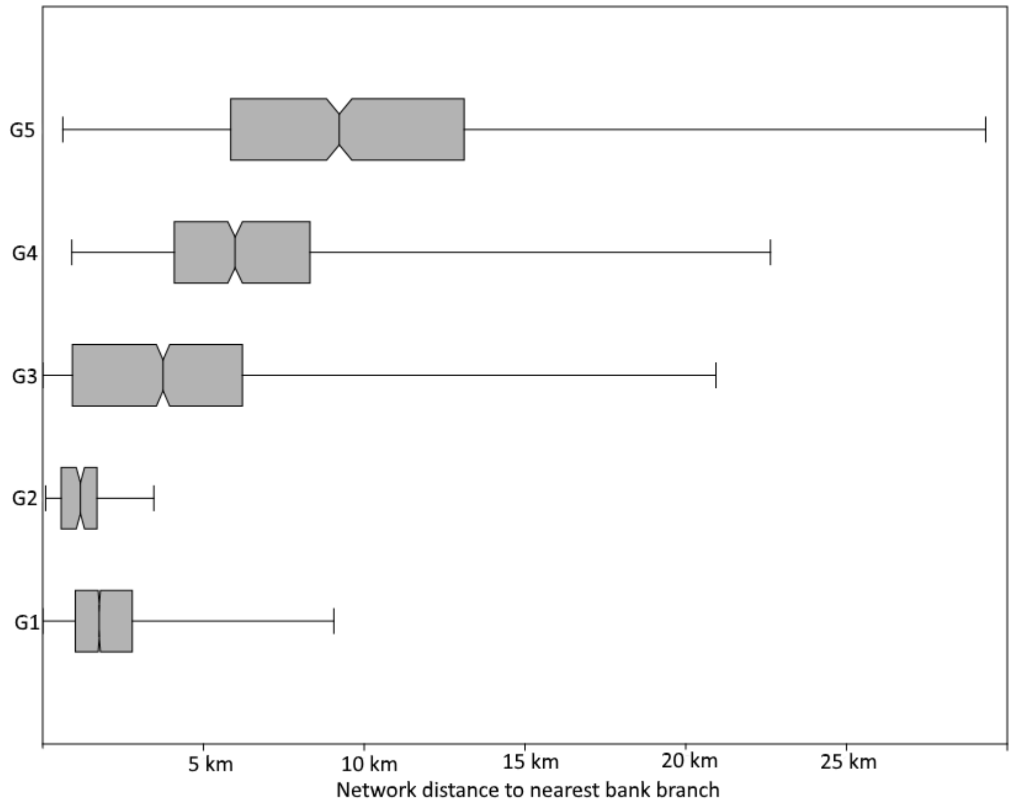

Figure 5: Network distances to nearest bank using the five-class OA classification

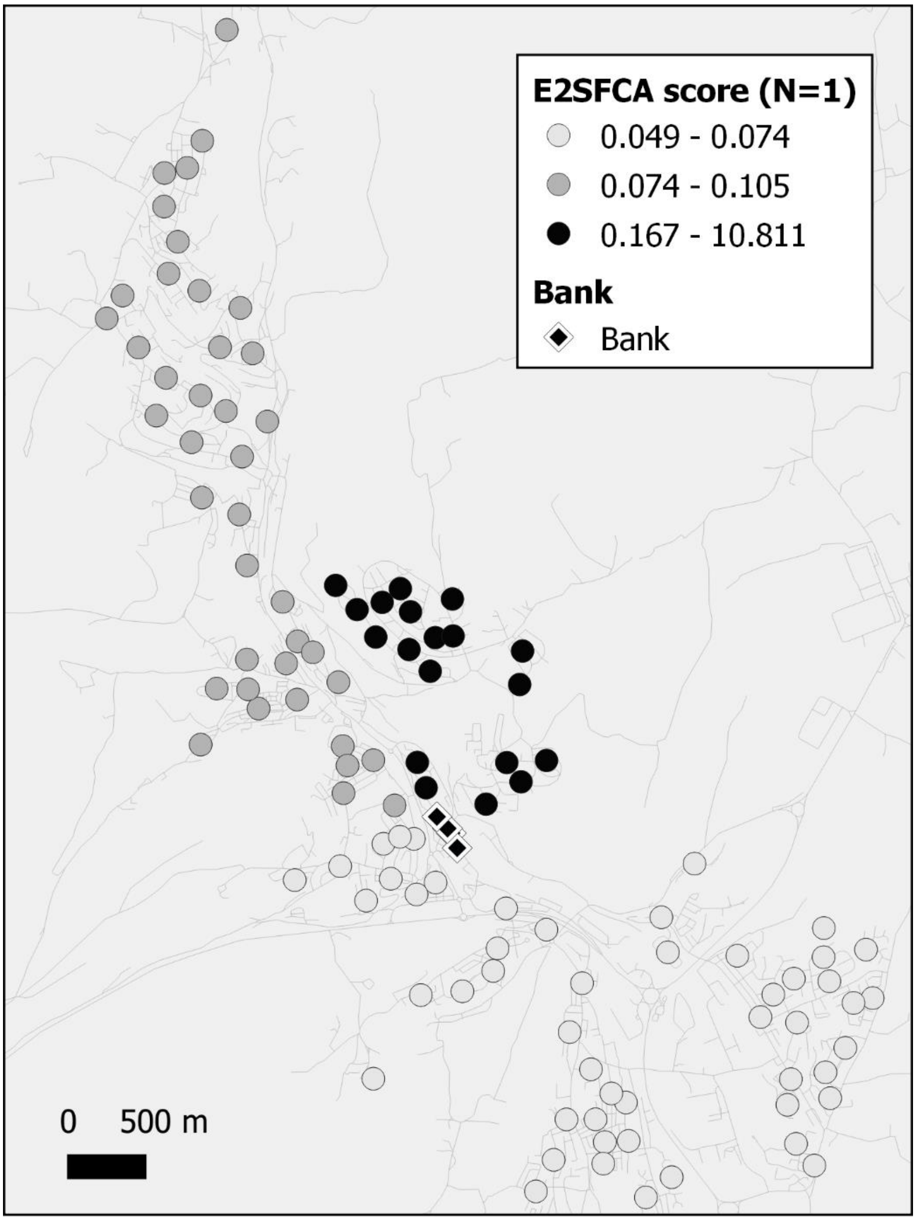

Figure 6: E2SFCA scores generated around a local cluster of bank branches when catchment sizes are set by the network distance to nearest branch (N=1).